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WING-FUSELAGE INTERFERENCE - COMPARISON OF CONVENTIONAL AND AIRFOIL-TYPE-FUSELAGE COMBINATIONS

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SUMMARY

Tests of wing-fuselage combinations employing an airfoil-type fuselage were made in the variable-density wind tunnel as a part of the wing-fuselage interference program being conducted therein. The models were designed to simulate an existing moderate-size transport airplane of that type. The test results showed that for such sizes, at least, the airfoil-type-fuselage combination should be well faired in such a way as to eliminate the discontinuity at the ends of the fuselage, and even then will probably have to rely largely on other than basic aerodynamic considerations for its justification.

INTRODUCTION

A comprehensive investigation of wing-fuselage interference is in progress in the N.A.C.A. variable-density tunnel. Results of parts of the investigation have been reported in references 1 and 2. The general program is outlined in reference 1. As a part of the program, a wing-fuselage combination consisting of one of the standard wings combined with an airfoil-type fuselage was briefly investigated.

The airfoil-type-fuselage combination is characterized by an enlarged and thickened central portion of the wing. This central portion is made sufficiently large and thick to accommodate the passengers and cargo and otherwise to take the place of the usual fuselage. The tail surfaces are carried on booms.

The airfoil-type-fuselage combination obviously becomes aerodynamically desirable when, for large airplanes, the space and height requirements of the fuselage portion are such that it becomes substantially an integral part of an efficient wing. The whole combination then becomes simply a flying wing, the characteristics of which should be readily predicted from airfoil-section data and wing theory. The type of combination that has been used in moderate-size transport airplanes, however, requires special investigation. It is characterized by a markedly thickened and enlarged central portion of the wing having substantially flat sides. The principal object of the present investigation was to compare this type of combination with one of the best wing-fuselage combinations of the conventional type.

DESIGN OF MODEL

The principal design requirements were: First, that the proportions should be somewhat like those of an actual airplane of the airfoil-fuselage type; and second, that the wing-fuselage combination should be directly comparable with some of the conventional combinations previously investigated. The combination was therefore designed around the N.A.C.A. 0018-09 tapered airfoil (reference 1). The ratio of fuselage chord to fuselage span and the ratio of fuselage thickness to fuselage chord (23 percent) were taken from the Burnelli UB 14A airplane (reference 3). The fuselage chord was then adjusted to give the airfoil-type fuselage the same useful volume as the conventional fuselage previously employed, considering only the forward 60 percent of the conventional fuselage to represent useful volume. This procedure gave:

	Airfoil-fuselage model	UB 14A
$\frac{\text{Fuselage span}}{\text{Wing span}}$	0.184	0.175
$\frac{\text{Fuselage chord}}{\text{Wing chord at juncture}}$	1.70	1.67
$\frac{\text{Fuselage area}}{\text{Basic wing area}}$	0.379	0.407

With regard to the details of the model lay-out (see figs. 1 and 5), existing airplanes of the airfoil-fuselage type were simulated. The fore-and-aft position of the fuselage was chosen to bring the fuselage quarter-chord axis in line with that of the wing in the plan view. The angular setting of the fuselage was chosen to make the zero-lift direction for the fuselage parallel to that of the wing. The height of the wing with respect to the fuselage was adjusted so that the upper surface of the wing, beginning somewhat behind the leading edge, as shown in figures 1 and 5, could be made continuous with the upper surface of the fuselage. The fuselage was formed from the N.A.C.A. 0023 section slightly altered to meet the condition just mentioned; namely, that the upper surfaces of wing and fuselage should be continuous. The practically symmetrical fuselage sections were employed because airfoil tests in the variable-density tunnel have indicated that sections of this thickness may have their characteristics definitely impaired by the use of camber.

As the combination of the wing and airfoil-type fuselage does not provide a suitable mounting for the tail surfaces, tail booms simulating those employed on the UB 14A were included on the model. In order to make the model comparable with the conventional combination, the tail booms were made long enough to provide a tail-mounting position at the same distance behind the wing as for the conventional combination.

The combination was also modified to include two types of fillets: First, small fillets between the wing and fuselage near the leading and trailing edges of the wing shown in figures 3 and 6; and second, large fillets, which are shown in figures 3 and 7, so designed that the discontinuity between the wing and fuselage would be eliminated as completely as possible without unduly increasing the frontal area.

TESTS AND RESULTS

The tests and the methods employed for the presentation of results are substantially the same as those described in reference 1. The results presented in figures 2 and 3 and in table V (a continuation of table V in references 1 and 2) are thus intended to be directly comparable with published results of tests of wing-fuselage interference conducted in the N.A.C.A. variable-density tunnel. All the coefficients are calculated on the basis of the original, or basic, wing area of 150 square inches.

DISCUSSION

General comparison.- Obviously these results, as compared with those from tests of the conventional-fuselage combination, do not supply conclusive evidence on which to base a final comparison of the relative merits of the airfoil-type-fuselage airplane. No engines, cowlings, radiators, tail surfaces, or windshields were included. Some favorable interference effects might result from the combination of the engine installation with the thick wing sections forming the fuselage. On the other hand, the propeller interference would almost certainly be unfavorable, but the possible small distance between the propeller thrust axes might be an important consideration.

Factors other than aerodynamic ones may also affect the comparison as, for example, structural considerations, landing-gear space, simplicity, window space, and passenger or cargo accommodations. Finally, there is nothing fixed with regard to the relative dimensions of the wing and fuselage. The present tests have also shown that the combination is sensitive to filleting, so that the comparison would undoubtedly be affected by further fillet modifications. Nevertheless, the results of the present tests should throw some light on the question of the inherent relative merit of the airfoil-type-fuselage combination.

Lift distribution and induced drag.- The type of combination under consideration has been widely discussed with respect to the lift carried by the fuselage. Such discussions have often implied that the conventional-type fuselage in a wing-fuselage combination does not carry lift as it should. The results of reference 1 indicate that this point of view is not in accord with experiment. The observation that the conventional combination at a given angle of attack gives more lift than the wing alone at the same angle of attack (see fig. 2) indicates, in fact, that the fuselage tends to carry too much lift. This characteristic is accentuated by an airfoil-type fuselage. In general, the departure from the span load that is aerodynamically best will be increased by any "extra" lift developed near the center span by the fuselage. The extra lift, however, is not large, owing to the low aspect ratio of the fuselage portion and to the reduced lift-curve slope for the very thick airfoil section. Its small magnitude is indicated by the small increase of lift-curve slope shown for this type of combination in figure 2.

Nevertheless, the extra lift might be of some value if it tended to add to the lift at the maximum. Figure 2 does show a gain in the maximum lift coefficient but it is small as compared with the added lifting surface provided by the airfoil-type fuselage.

In order to investigate further the extra lift and the excess induced drag associated with it, the load distribution was calculated from wing theory by the method given in reference 4. The calculated load distribution is presented in figure 4. The calculated lift-curve slope is 0.078 and agrees within 1 percent with the experimental value (0.078 from fig. 2 corrected for tunnel-wall interference). The agreement of the calculated and experimental lifts indicates that the load-distribution calculations are satisfactory.

The results show that the fuselage part of the lifting surface, comprising 33 percent of the total lifting area (exposed wing area plus fuselage area) contributes 26 percent of the total lift. Nevertheless, the excess induced drag, which must be attributed mainly to the concentration of too much lift near center span, is 8.5 percent as compared with the induced drag of the ideal wing of the same span and at the same lift; that is, the corresponding elliptically loaded wing giving minimum induced drag. The corresponding excess for the plain wing alone (2:1 taper, orthogonal tips) is 1.1 percent. It is not feasible to make this calculation for the conventional fuselage combination.

Drag in high-speed flight.- The minimum drag coefficients from figures 2 and 3 or from table V may be taken as representative of the drag in high-speed or cruising flight. The coefficient representing the "drag and interference" due to the airfoil-type fuselage is thus found from figure 2 to be 0.0068 as compared with 0.0022 for the conventional fuselage. The minimum drag coefficient of the combination may be compared with the coefficient computed from the drag of the component parts, neglecting interference. The component drag coefficients are individually estimated as follows:

Profile drag of fuselage sections	0.0041
Tip drag for fuselage portion (reference 5)	.0047
Skin friction on tail booms	.0004
Drag of exposed part of wing	.0068
Tip drag for rectangular wing tips	.0001
Calculated total	.0161
Experimental total	.0161

The admitted fortuity of the agreement does not detract from the value of the principal conclusion, drawn from a consideration of the relative magnitude of the components of the calculated minimum drag coefficient, which is that excessive drag results from the discontinuity between the wing and fuselage, that is, from the tip drag of the fuselage portion. The discontinuity producing the most marked drag increment must be that due to the sharp upper-surface corner of the fuselage ahead of the wing. The importance of this disturbance is indicated by the marked improvement (reduction from 0.0161 to 0.0145, fig. 3) that resulted from the addition of small nose fillets that eliminated some of the sharp fuselage corner (fig. 6). The drag was further reduced (to 0.0135) by the large fillets, which eliminated all the sharp fuselage corners and faired out the discontinuity (fig. 7), in spite of the fact that the fillets increased the frontal area. Much greater drag reduction seems unlikely owing to the high-drag airfoil sections employed for the fuselage.

The obvious conclusion reached is that such a well-faired combination necessarily becomes favorable for large airplanes, if the design conditions permit modification of the proportions to the extent that the combination becomes a well-designed flying wing without excessive center-section chord and thickness. With the present proportions, however, even with the large fillets, the minimum drag and interference due to the airfoil-type fuselage remains 1.9 times that due to the conventional fuselage in the combination used for comparison. The maximum lift coefficient is 13 percent higher for the airfoil-type-fuselage combination with favorable fillets. The speed-range index is 127 as compared with 132 for the conventional combination.

It appears, then, that the airfoil-type-fuselage combination of the present proportions must be well faired in such a way as to eliminate the discontinuity at the ends of the fuselage, and even then will probably have to rely largely on other than basic aerodynamic considerations for its justification.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 15, 1937.

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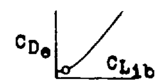
Table V.- Principal aerodynamic characteristics of wing-fuselage combinations.

Diagrams representing combinations	Combination	Remarks	Longitudinal position d/c	Vertical position k/c	Wing setting i_w Degrees	Lift-curve slope (per degree) a A.R.= 6.86	Span efficiency factor e	$C_{D_{e_{min}}}$	$C_{L_{opt}}$	Aerodynamic center position n_o	C_{m_o}	Lift coefficient at interference burble [1]$C_{L_{ib}}$	[2]$C_{L_{max}}$ effective R.N. = 8.2×10^6	[2]$C_{L_{max}}$ effective R.N. = 3.7×10^6
Tapered N.A.C.A. 0018-09 airfoil with airfoil type fuselage.														
		Wing alone				0.077	0.90	0.0093	0.00	0.020	0.000	[A]1.4	[c]1.48	[c]1.23
	268		0	0.15	0	.080	[5].80	.0161	.00	.024	-.002	[A]1.5	[c]1.54	[b]1.28
	269	With small fillets	0	.15	0	.082	[5].85	.0145	.03	.029	-.008	[A]1.6	[c]1.62	[b]1.27
	270	With transition fillets	0	.15	0	.085	[5].90	.0135	.05	.037	-.015	[A]1.7	[c]1.72	[b]1.34
Tapered N.A.C.A. 0018-09 airfoil with round fuselage.														
	186	(Comparison comb. ref. 1	0	0	0	.079	.90	.0115	.00	.040	.000	[A]1.5	[c]1.52	1.25

1 Letters refer to types of drag curves associated with the interference burble, as follows:

Type A

Type B

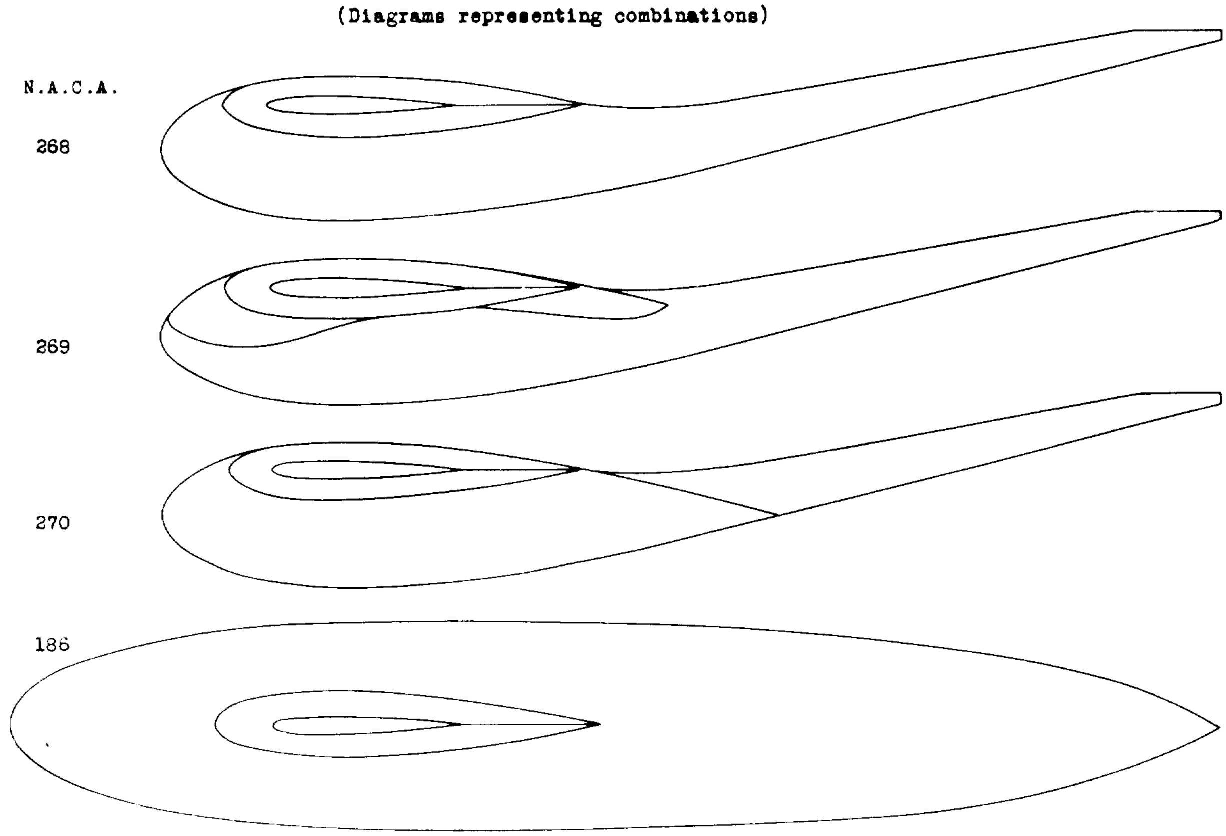


Type C

2 Letters refer to condition at maximum lift as follows,
- a Reasonably steady at $C_{L_{max}}$
- b Small loss of lift beyond $C_{L_{max}}$
- c Large loss of lift beyond $C_{L_{max}}$ and uncertain value of $C_{L_{max}}$

3 Poor agreement in high-speed range.
4 Poor agreement over whole range.
5 Poor agreement in high-lift range.
6 Rapid increase in drag preceding definite breakdown.

(Diagrams representing combinations)



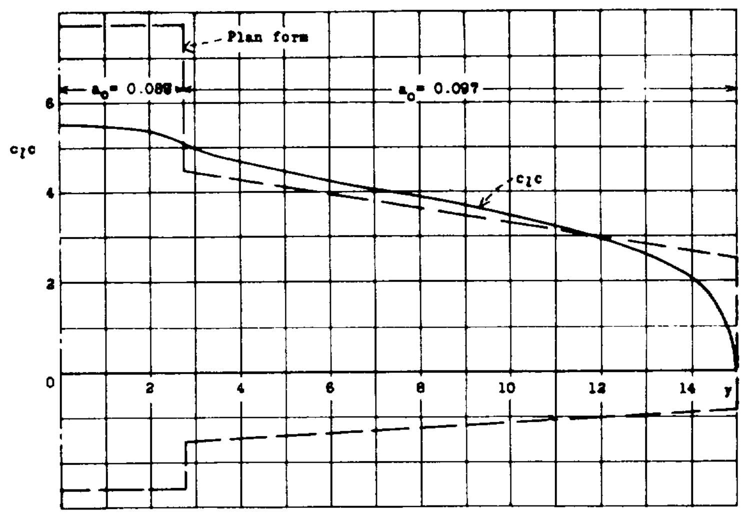


Figure 4.- Span load distribution for airfoil-type-fuselage combination.

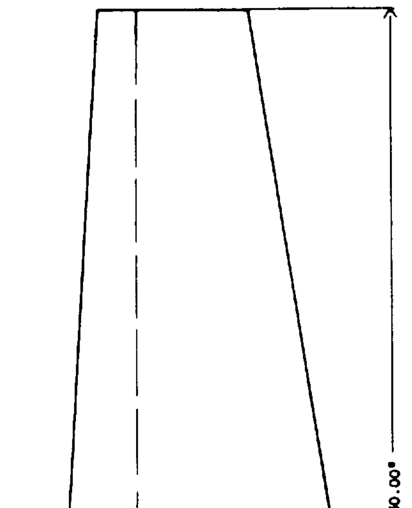
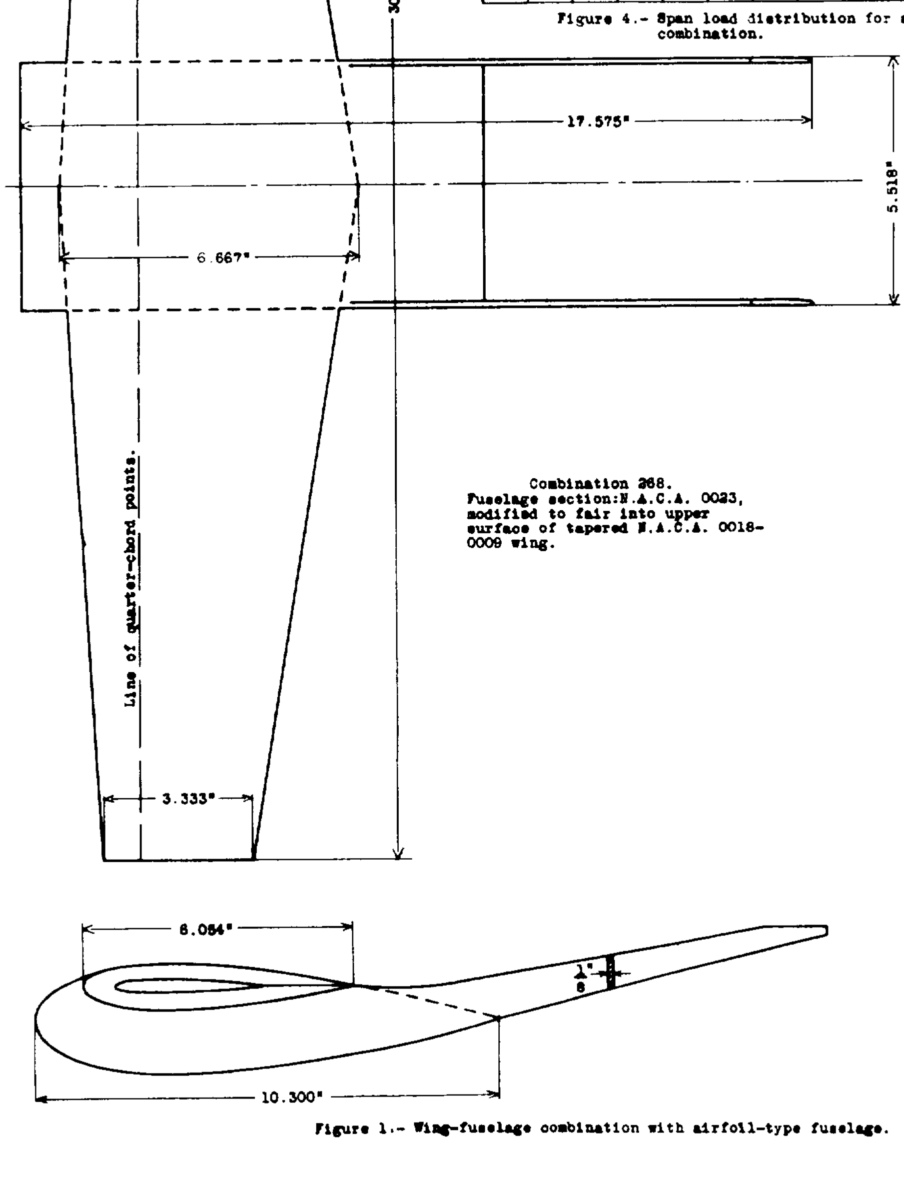



Figure 1.- Wing-fuselage combination with airfoil-type fuselage.

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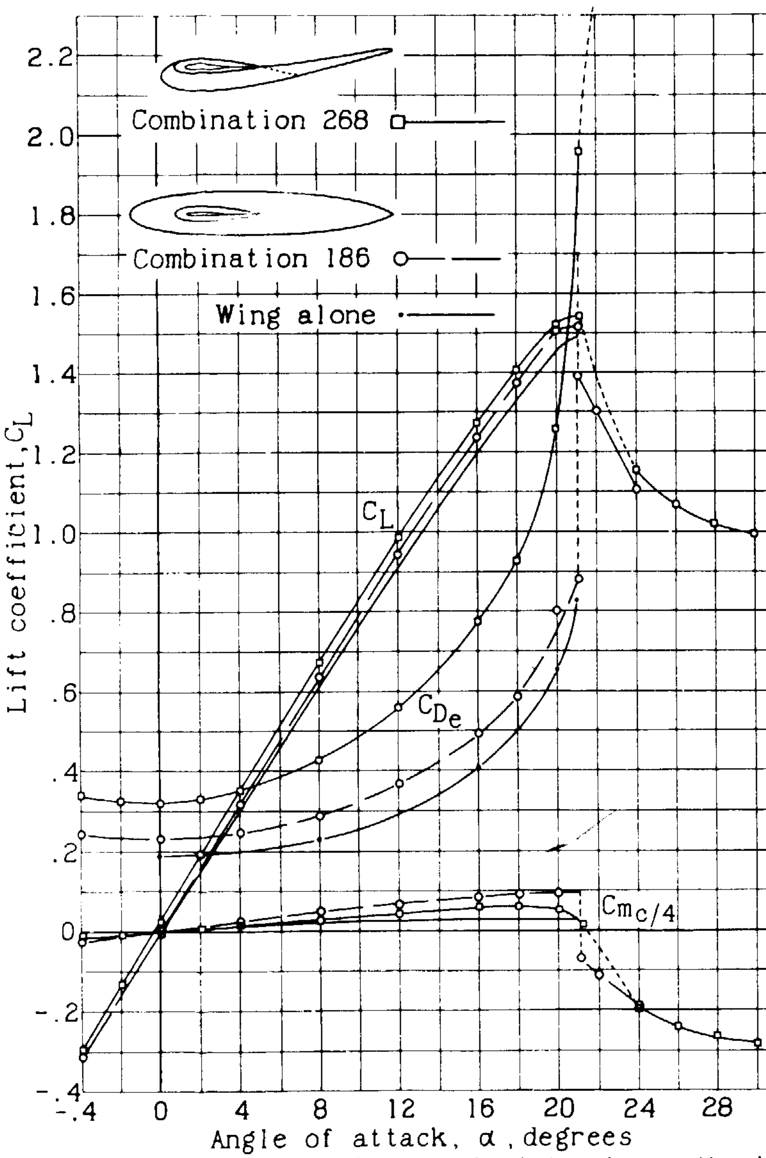

Figure 2.- Comparison of airfoil-type fuselage and conventional wing-fuselage combinations.

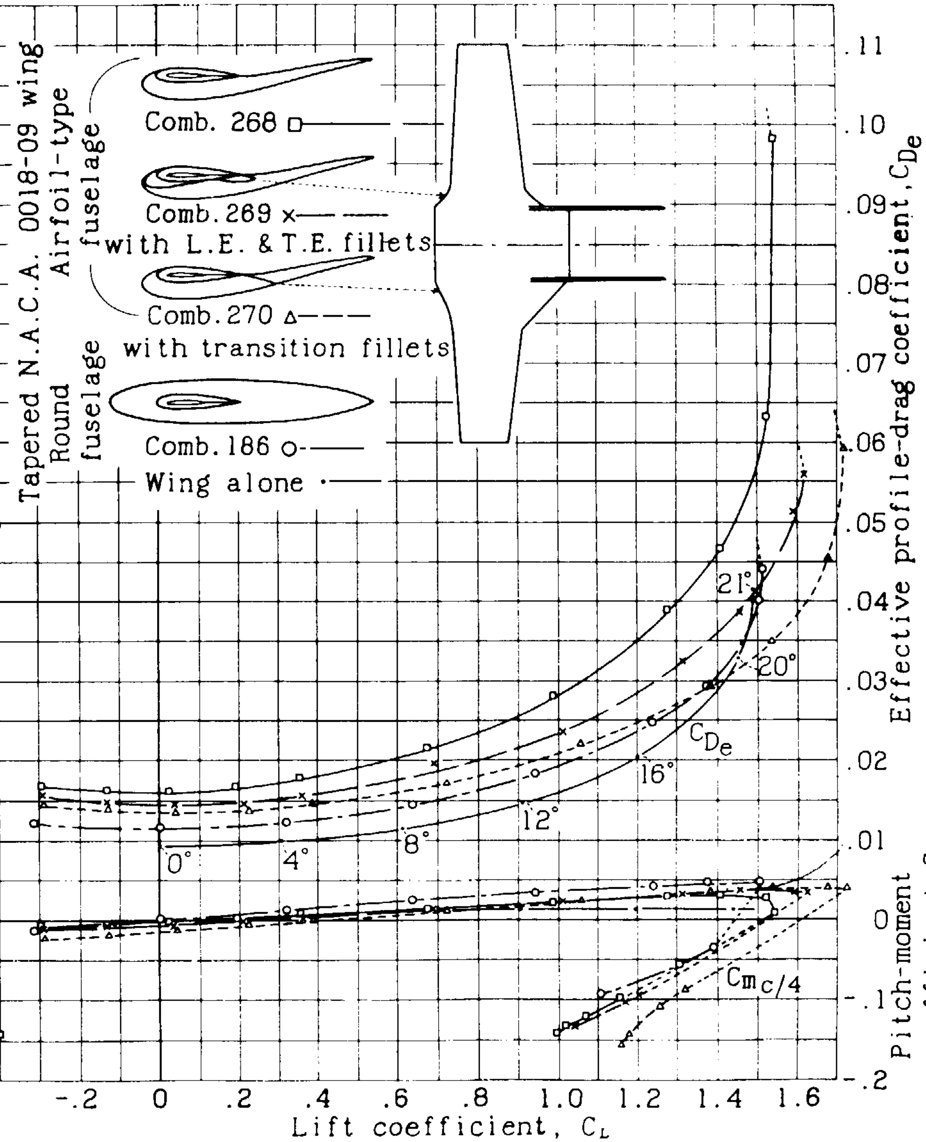

Figure 3.- Effect of fillets on the characteristics of the airfoil-type fuselage combination.

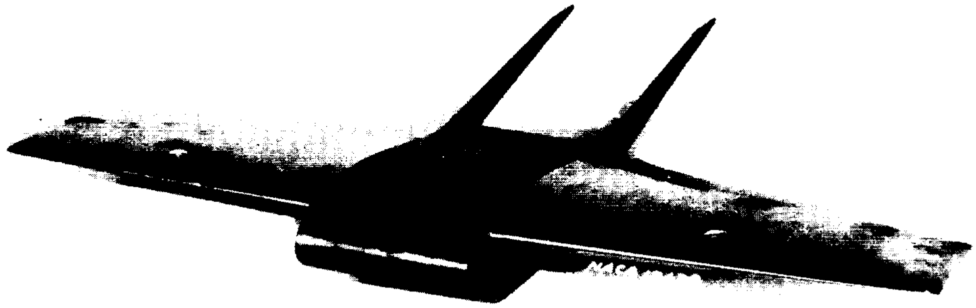

Figure 5.- Airfoil-type fuselage combination.

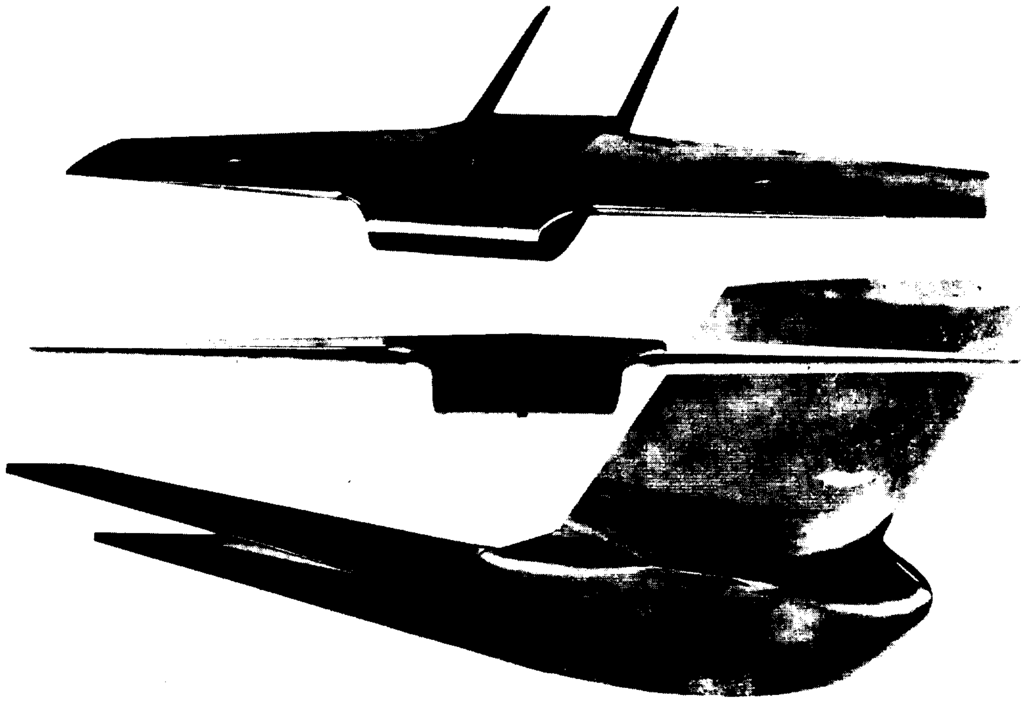

Figure 6.- Combination with small fillets.

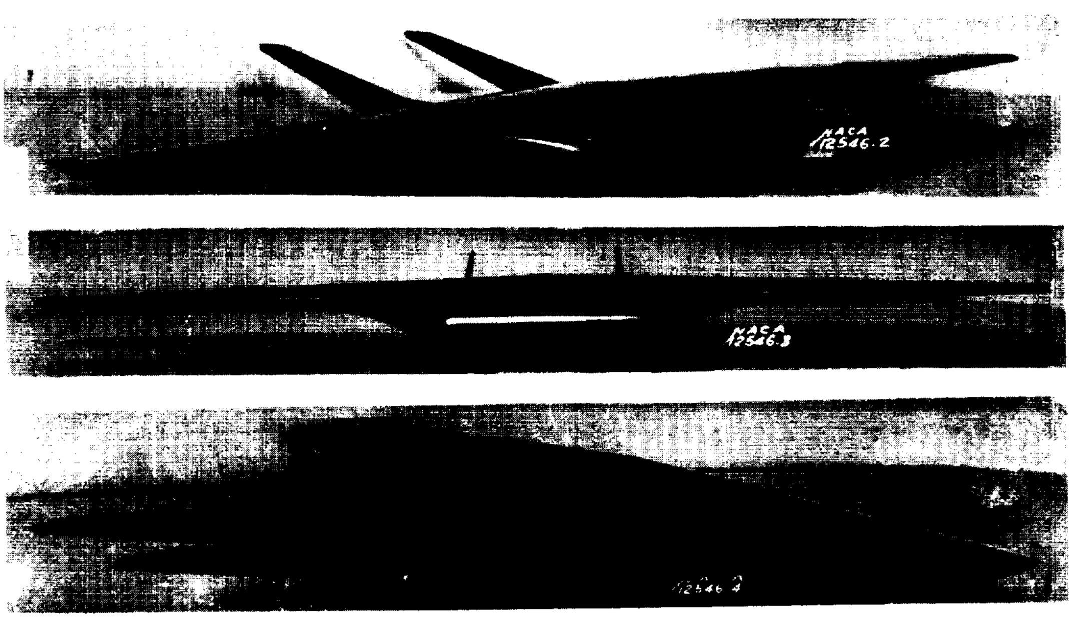

Figure 7.- Combination with large fillets.